

## TABLE 4- COMMUTER BUSES (DUAL-FUEL)

### Demonstration of Caterpillar C10 Dual Fuel Engines in Commuter Buses: **Successes, Challenges and Market Opportunities**

High-fuel use, high-mileage heavy-duty vehicles represent an ideal opportunity for alternative fuels (i.e. natural gas) use. Fuel storage requirements, performance deficiencies, limited fueling access and increased cost impede alternative fuel use by these vehicles. **Improvements in** engine, vehicle and infrastructure technologies lower these barriers and leverage **the** clean air benefits that natural gas engines offer. Optimized dual-fuel **engine** technologies are narrowing the horsepower, fuel economy and cost gaps between natural gas and diesel engines for heavy-duty vehicle applications. Demonstrating **these** technologies in selected applications enhance their commercialization prospects, yielding tangible clean air and petroleum displacement benefits.

The Santa Barbara County Air Pollution Control District (**SBCAPCD**) operates a Clean Air Express Commuter Bus **Program** designed to **reduce** pollution from single-occupant commuter passenger vehicles operating between Santa Barbara, **Lompoc, Buellton**, Santa Maria, Santa Ynez and Ventura, California. The program uses "Greyhound" type inter-city buses. To advance its goal to reduce petroleum use in California's transportation sector through alternative fuel vehicle technology demonstrations, the California Energy Commission teamed with the **SBCAPCD** to demonstrate higher horsepower (**>350HP**) natural gas engine technologies in Santa Barbara, California. Prior to the demonstration, there **were** no commercially available natural gas engines with a 300 horsepower or **higher** rating for **vehicles**. The demonstration was **funded** with a \$150,000 grant from the U.S. Department of Energy's Sustainable Technology Energy Partnership (STEP) Program administered by the National Renewable Energy Laboratory (NREL). The Federal Transit Administration, the City of Lompoc, Southern California Gas Company and **Melni** Bus Company cosponsored the \$1.8 million project.

The purpose of the demonstration was to **verify** the performance and suitability of higher horsepower natural **gas** engines for heavy-duty vehicle applications.

Four new 1997 model-year Motor Coach Industries 102DL3 commuter buses equipped with 350 **HP** Caterpillar **C10** were demonstrated in Santa Barbara, California. Three **buses** were converted to operate on a mix of natural gas and diesel using the Clean Air Partners/Power Systems Associates natural gas fuel system. The fourth bus was used as a **diesel** control. The 1997 Caterpillar **C10** dual-fuel engine is certified to the California Air Resources Board alternative low NOX emission standard of 2.5 **grams/brake** horsepower-hour. The Caterpillar **C10** dual-fuel engine starts and idles on diesel. As engine load increases beyond idle, up to **85** percent of the **diesel fuel** is **replaced** by port injection of compressed **natural** gas. Performance (power, torque, acceleration), fuel economy, emissions and operating costs data were collected and analyzed over 94,000 **miles** of operation **during** the 12-month demonstration. The diesel control bus covered about 27,000 miles and was removed **from** service to be converted to dual-fuel operation. Based on the data collected, the dual-fuel buses performed **as well as** the **diesel** control bus, had lower regulated pollutants - oxides of nitrogen and particulate matter - and cost **three-cents** per mile **less** to operate than **the** diesel control bus, if the incremental cost of the **CNG** fuel system is eliminated. Power and torque characteristics of the dual-fuel buses maintained performance levels similar to the diesel control bus.

This first on-highway use of the Caterpillar dual-fuel engines in commercial service documented several successes, important challenges and underscored their market potential.

## SUCSESSES

Several important factors measure the success of alternative fuel vehicle technologies compared to gasoline or diesel vehicles.

**Performance and Reliability.** The dual-fuel buses did not experience downtime due to mechanical failure of any CNG components or fueling system. These observations do not extend beyond the 12-month demonstration period. Although they perform well in selected applications, transit buses in particular, natural gas vehicles do not have a long operating history as diesel or gasoline engines to evaluate their long-term reliability.

**Fuel Economy (Efficiency).** The in-use fuel economy of the dual fuel buses averaged 5.3 miles per gallon of diesel equivalent, which was about 10 percent less than the 6.0 miles per gallon for the diesel control bus. This ten-percent difference in fuel economy is an improvement over earlier dual-fuel and spark-ignited natural gas engine technologies with in-use fuel economy that can be as high as 30 percent less, than similar diesel powered vehicles in some applications.

**Emissions.** Natural gas engine technologies generally emit lower levels of some criteria pollutants than comparable diesel engines. Compared to the diesel control bus, initial emission test data showed the dual-fuel buses had 27 to 58 percent lower oxides of Nitrogen emissions and 54 to 65 percent lower particulate emissions depending on the emission test cycle. Carbon dioxide emissions were 6.3 to 8.6 times higher, Total hydrocarbon emissions were also higher than expected for the dual-fuel engines compared to the diesel control. Non-methane hydrocarbon data are still being evaluated. These initial results show the promising emission reduction benefits possible from dual-fuel engine technologies for some criteria pollutants of greatest concern to California air quality officials.

**Operating Costs.** Cost savings opportunities are attractive to heavy-duty vehicle operators. The demonstration data show that the incremental cost associated with configuring the buses to operate on dual fuel added to the cost per mile of operation. Accounting for insurance, fuel costs, fueling labor cost, CNG fuel-system maintenance cost, oil changes, a 12-year vehicle useful life at a 3 percent interest rate, the dual-fuel buses cost about 20 cents more per mile to own and operate than the diesel control buses. Without the incremental cost of the natural gas system, the dual-fuel buses would cost about 3 cents per mile less to operate than the diesel control at fuel and insurance prices prevailing during the demonstration. Incentives that defray incremental cost of natural gas vehicles stimulate their use and advance Clean Cities goals.

**Implications of the Demonstration.** Heavy-duty vehicles make up about 2 percent of California's vehicle population but consume about 16 percent of the on-road transportation energy and contribute disproportionately to mobile source particulate (> 50 percent) and oxides of nitrogen (~40 percent) emissions. Potentially cleaner engine technologies such as the Caterpillar C 10 dual-fuel engine which use alternative fuels provide options for reducing

California's transportation sector dependence on petroleum fuels and harmful emissions from heavy vehicles. The performance of this engine in the Santa Barbara demonstration has generated high interest in California on the part of the engine supplier and agencies responsible for administering California's newly created Carl Moyer Memorial Program. The program offers up to \$25 million in state incentives to pay for the incremental cost of engine technologies that reduce NOX emissions by at least 25 percent or 30 percent below applicable emission standards,

### CHALLENGES

The demonstration documented challenges that still affect the successful use of alternative fuel vehicle technologies.

**Fuel Availability and Vehicle Operator Commitment to Alternative Fuel Use.** The Santa Barbara dual-fuel buses operated in the diesel only mode on several occasions during the demonstration. In addition to CNG fuel system computer malfunction that caused the buses to operate on diesel only occasionally, limited access to a reliable fueling facility also reduced the total natural gas consumed during the demonstration. The dual-fuel buses operated on diesel fuel when the primary CNG fueling station was out of service. With limited CNG availability, the dedication of the vehicle operator was necessary to fuel the vehicle and achieve the 56 percent CNG share of total energy used during the demonstration.

### LESSONS LEARNED

**Technology improvement.** Power Systems Associates can improve the Caterpillar C10 dual-fuel engine in several areas. A crucial area of improvement is to make the engine resume operating on CNG and diesel when it unexpectedly defaults to the diesel-only mode. The dual-fuel engine operated in the diesel-only mode when the CNG system computer determined specified operating parameter limits were exceeded. Power Systems has developed new controls that command resumption of dual-fuel operation after a specified period. The company plans to incorporate the new control regime on 1999 model year C10 and C12 dual-fuel engines.

### MARKET OPPORTUNITIES

The market opportunity for dual-fuel engine technologies is potentially large. In 1997, there were approximately 115,000 Class 7 (26,001 to 33,000 pounds GVWR) and 180,000 class 8 (33,001 pounds GVWR and above) vehicles sold in the United States (Automotive News, January 26, 1998, p. 22). In 1997, there were over 850,000 registrations (Travel and Related Factors in California, 1997 Annual Summary) of heavy-duty vehicles in California. Dual-fuel engine technologies can be used in trash truck, bus and line-haul truck applications. The California programs to reduce NOX and particulate emissions from heavy vehicles in the state drive the market opportunities for dual-fuel engine technologies. Programs such as California's Carl Moyer Program which provide incentives to retire heavily polluting diesel engines from California's roads improve the market prospect for cleaner engine technologies in truck and bus applications. The combination of end-users interested in cleaner engine technologies and the availability of incentive funds increase the prospect of positive market growth for alternative fuels. The fraction of the 26,000 to 28,000 commercial buses operating in California represent an immediate potential market for cleaner engine technologies such as the Caterpillar C 10 dual-fuel engines.